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RECOVERY OF HEAVY OILS THROUGH IN-SITU COMBUSTION PROCESS

BACKGROUND OF THE INVENTION

The present invention relates to the field of recovery of oil from oil wells, and provides an improved method for recovery of oil previously considered unrecoverable.

Oil formations typically include portions in which the oil is present in liquid form, and portions in which the oil is trapped in a solid or semi-solid form, such as a tar, bitumen, or asphalt. Some oil exists in a heavy, viscous form, which is difficult or impossible to pump out. The oil in the liquid form can be pumped out relatively easily, but it is much more difficult, and expensive, to extract the heavy oil. It is especially difficult to extract the oil that is contained within a solid material; in their natural state, materials such as bitumen will not flow at all. For these reasons, in the prior art, when the liquid in a formation has been substantially recovered, the oil well has been declared spent, and the remaining oil has been deemed unrecoverable.

It turns out that, for many oilfields, the amount of oil deemed unrecoverable may be as great as, or substantially greater than, the portion that is easily recoverable. Thus, if it were possible to recover, economically, all of the purportedly unrecoverable oil in known oilfields, the amount of proven petroleum reserves available to the world would increase by a very substantial amount.

It has been proposed, in the prior art, to recover heavy oil, and oil

found within solid materials, by heating the underground formation itself, and thereby causing heavy oil to become less viscous, and/or causing oil trapped within a solid material to flow out of the material. In effect, heating causes formerly unrecoverable oil to become ordinary, liquid crude oil, which can be pumped out by conventional means.

An obvious problem with the concept of heating an oil reservoir is that it is difficult to heat a formation that may be hundreds of feet, or more, below the ground. One prior art method of providing such heat has been to generate steam at the surface of a well, and to pump the steam into the well to heat the formation.

A disadvantage of the use of steam is that the process requires a large amount of energy, mainly through the burning of natural gas to produce the steam. Also, because steam tends to rise, it tends to flow above, or override, the oil reservoir into which it is injected, thereby missing much of the formation intended to be heated. As a result, the steam heating process may recover only about 30% of the oil in the reservoir.

The problem of steam override can be reduced by providing separate horizontal wells, wherein the steam is injected into an upper well, and so that the resulting liquid oil flows by gravity to a production well disposed below the first well, allowing the liquid oil to be pumped out. The latter process is an improvement over other steam heating methods, as it allows about 40-60% recovery, but it still requires burning of natural gas at the surface.

To overcome the problems associated with steam produced at the surface, it has been proposed to heat the formation "in-situ", i.e. at the location of the formation. In theory, one can start an underground fire, combusting a small part of the formation. The fire is supported by

compressed air injected from the surface. If the compressed air is hot enough, it can ignite the formation and support combustion. Combustion of a portion of the formation generates heat which heats other portions of the formation, thereby causing the oil in the formation to become an extractable liquid.

In practice, in-situ combustion is difficult to manage, and has achieved only marginal results, with about 30% recovery at most. Clearly, one seeks to burn only a small part of the formation, leaving uncombusted liquid oil to be pumped out. It is difficult to limit the scope of in-situ combustion in this way. Also, it is important to be able to control the propagation of the combustion within the formation. One might start a fire in a part of the reservoir, but the fire might move in random directions, based on fracture patterns in the formation. In the worst case, the combustion might destroy the very oil that one seeks to recover. Control of the propagation of in-situ combustion is inherently difficult.

An improved process for in-situ combustion of an oil formation is described in U.S. Patent No. 5,626,191, the disclosure of which is incorporated by reference herein. In the patented process, a vertical injection well is positioned near a production well having horizontal and vertical portions. The production well has the general shape of a foot, and therefore defines a "toe" portion and a "heel" portion. The injection well provides a path for injection of air near the toe portion of the production well, and the air, and the combustion front, proceeds laterally, from the toe to the heel. This in-situ combustion process is sometimes called TTH, for "toe-to-heel" combustion. More recently, the process has been known in the industry by the acronym THAI, meaning "toe to heel air injection".

An improvement to the THAI process is described in U.S. Patent No. 6,412,557, the disclosure of which is also incorporated by reference herein. The latter patent discloses a catalyst deposited in the gravel pack surrounding the production well. The catalyst, which is similar to catalysts used in conventional refineries, not only provides better control of the combustion process, helping to prevent the entire formation from being burned, but it also chemically upgrades the oil before it even comes out of the ground. In particular, the catalyst supports reactions that separate undesirable substances, such as sulfur, asphaltenes, and heavy metals, from the oil. Moreover, the process inherently burns unwanted coke while the oil is still underground. In prior art processes, the coke would have to be removed at the surface. The remnants of the burnt coke seal the horizontal portion of the well. The process including the catalyst is known in the industry as THAI/CAPRI.

The THAI/CAPRI process has further advantages over prior art in-situ combustion methods. Entrained gases such as nitrogen rise with the oil to the surface, and can be separated from the oil and sold. Residual heat from the oil can be bled off to produce power. Water produced in the process can be used for irrigation without additional treatment. And the process does not require burning of natural gas at the surface, making the process more environmentally benign. The major requirement is only a source of compressed air, and means for forcing it into a reservoir.

It is believed, based on the results of computer simulations, that the THAI/CAPRI process could recover as much as 80% of the oil trapped within a reservoir, and previously deemed unrecoverable. A recovery percentage this high has been unattainable in the prior art.

An important ingredient of the THAI/CAPRI process is compressed air which is injected into the formation. In the prior art, such air has been

derived from ambient air that has been compressed and stored in a cylinder or other container. Alternatively, combustion air could be supplied by vaporizing liquid oxygen, and combining it with ambient air or nitrogen, before injecting it into the formation. But cryogenic systems are expensive, difficult to transport, and require regular maintenance, which can be especially difficult in remote areas.

The present invention provides an improvement of the above process, by providing a more desirable means of generating an oxygen-rich gas for supporting in-situ combustion.

SUMMARY OF THE INVENTION

The present invention comprises an improved in-situ combustion process for recovery of oil from a formation. The in-situ combustion process generates heat which causes heavy oil in a reservoir to become less viscous, and thus to flow readily to a location from which it can be pumped out. In-situ combustion is also used in order to release oil that is trapped in a solid or semi-solid material, such as bitumen.

An in-situ combustion process requires that air be supplied to the location of the combustion. According to the present invention, the combustion air is oxygen-enriched air that is generated non-cryogenically above the surface and injected into a well. The oxygen-enriched air may be produced by a membrane system or a pressure swing adsorption (PSA) system. Preferably, the oxygen-enriched air is compressed before being injected into the well.

The non-cryogenically produced oxygen-enriched air may be blended with ambient air, or other air, so as to produce a gas having a desired oxygen

content. In this way, the oxygen content of the gas can be easily adjusted to suit the requirements of the particular application.

The membrane or PSA system produces an oxygen-enriched stream and an oxygen-depleted stream. In another embodiment, the oxygen-depleted stream, which is normally mostly nitrogen, can be used to operate a compressor for compressing the oxygen-enriched stream before it is injected into the well. The nitrogen could be used instead for other purposes.

The present invention is especially useful with a toe-to-heel combustion process, which is a process in which air is conveyed into an injection well, to support combustion in a horizontal well having an identifiable "toe" and "heel" structure. The present invention provides oxygen-enriched air in the latter process, instead of ordinary air. The invention is also useful in an improved version of the toe-to-heel combustion process, in which the process employs a catalyst which chemically upgrades the oil before the oil is pumped out of the ground.

The present invention therefore has the primary object of providing an improved process for extracting heavy oil, and/or oil trapped in a solid or semi-solid material, from an underground formation.

The invention has the further object of providing an economical and convenient source of oxygen-enriched air, for use in an in-situ combustion process for oil recovery.

The invention has the further object of reducing or eliminating environmental hazards associated with an in-situ combustion process for oil recovery.

The invention has the further object of providing an improved process for oil recovery, wherein the process can be operated with equipment that is readily portable.

The invention has the further object of providing oxygen-enriched air

for use in an in-situ combustion process for oil recovery, wherein the oxygen content of the oxygen-enriched air can be easily adjusted to suit the requirements of the combustion process.

The reader skilled in the art will recognize other objects and advantages of the present invention, from a reading of the following brief description of the drawing, the detailed description of the invention, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWING

The Figure provides a schematic diagram of an apparatus used for practicing the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention includes a method and apparatus for providing oxygen-enriched air for use in recovering heavy oil, or oil that is trapped in a solid or semi-solid material, from an underground oil reservoir. The oxygen-enriched air is used in an in-situ combustion process, wherein the air is injected into a well to support combustion of a portion of the reservoir, so as to generate heat in the formation. The resulting heat causes the uncombusted oil in the vicinity of the combustion to become less viscous, so that the oil can flow to a location from which it can be removed by conventional means.

In particular, the present invention can be considered an improvement to the THAI, or THAI/CAPRI process, for oil recovery, described above.

More generally, the invention can be used with any in-situ combustion process, wherein a portion of an oil formation is combusted to heat an adjacent portion of the same formation. The invention is therefore not necessarily limited to use with THAI or THAI/CAPRI processes.

In its basic form, the invention comprises generating oxygen-enriched air, using a non-cryogenic process, above the surface of a well, and injecting the oxygen-enriched air downhole to support combustion underground. The non-cryogenic process preferably uses a gas separation membrane system or a pressure swing adsorption (PSA) system. The oxygen content of the oxygen-enriched air may be adjusted by mixing the oxygen-enriched air with ambient air, or other air, to obtain a stream having a desired percentage of oxygen. Controlling the percentage of oxygen provides additional control over the downhole combustion, and enables the operator to tailor the composition of the air to the parameters of the oilfield, including the type of oil to be recovered, the temperature of the reservoir, etc.

In another embodiment, the invention includes capturing the oxygen-depleted gas stream produced by the membrane or PSA system, and using this stream to drive a turbocompressor that further compresses the product oxygen-enriched gas.

The use of oxygen-enriched air, instead of ordinary air, in supporting in-situ combustion, has several advantages. Oxygen-enriched air reduces the amount of gas needed for combustion, because of its higher oxygen content. Because different reservoir sites have different parameters (i.e. type of oil, temperature, etc.), the same system can be used at different sites, possibly with different settings of the oxygen content of the injected air. Thus, the present invention effectively increases the number of viable reservoir sites from which oil can be recovered with the same

system. It is easy to adjust the oxygen content, simply by mixing the product oxygen-enriched gas with ambient air.

The use of oxygen-enriched air produced by a membrane or a PSA system has advantages over the use of a cryogenic system, in that membranes or PSA systems cost less than cryogenic systems, are more readily portable, and are easier to use. Membrane or PSA systems do not require costly equipment for storage and transport of cryogenic liquids.

The Figure provides a schematic diagram of the components of a system used to practice the present invention. Air compressor 1 takes ambient air and compresses it. The compressed air passes through receiver 2 and moisture separator 3. The air may then pass through an optional air dryer 4. The air passes through coalescing filters 5 and 6, and heater 7. Air leaving the heater may pass through an optional carbon bed 8, and then through particulate filter 9.

Air leaving the particulate filter enters air separator 10, which may be either a membrane or a pressure swing adsorption (PSA) unit. The air separator converts the incoming air into two streams, one which is oxygen-enriched and the other which is oxygen-depleted. In the extreme case, the separator may produce one stream that is virtually all, or nearly all, oxygen, and another stream which is almost all nitrogen. In the more general case, the separation of oxygen is less than complete.

The oxygen content of the output of the separator 10 may be controlled by blending air, which may be ambient air or other air, with the oxygen-enriched stream as it exits the separator. The Figure shows blending air being injected through conduit 13. Conduit 13 is preferably positioned upstream of all compressors in the system, so that the air streams may be blended at ambient pressure.

The resulting product stream comprising oxygen or oxygen-enriched air is compressed in compressor 12. The output of compressor 12 is a compressed oxygen-enriched gas stream, which is then directed to an injection well, for supporting an in-situ combustion process, as discussed above.

In an alternative embodiment, also illustrated in the Figure, the nitrogen (or, more generally, the oxygen-depleted gas stream produced by the membrane or PSA system) is used to drive a turbocompressor 11, which helps to boost the pressure of the oxygen-enriched product gas. The latter arrangement is especially useful in situations where the nitrogen (or oxygen-depleted air) is not needed, or not needed at pressure, since the normal operation of a membrane would yield nitrogen at near feed pressure of the membrane system.

Alternatively, the nitrogen (or oxygen-depleted gas) produced by the separator 10 can be used for inerting the oil product, or for any other use in which nitrogen or an oxygen-depleted gas is needed in the vicinity of an oil well. Such nitrogen could be used for enhancing oil recovery, for drilling, or for other uses.

The nitrogen or oxygen-depleted air produced by the separator could be discarded instead of being used as stated above. The present invention is intended to include this possibility also.

The method described above has significant advantages over the prior art. The components shown in the Figure can be provided in a housing which can be relatively easily moved from one oil recovery site to another. The use of oxygen-enriched air to support in-situ combustion can reduce the amount of gas needed to support such combustion, and can effectively increase the number of viable reservoir sites from which oil can be recovered.

Membrane systems can provide up to about 60% oxygen, while PSA systems can provide up to about 99% oxygen, using currently-available technology. Membrane systems may be preferred over PSA systems, in that by limiting the oxygen content to 60%, it may be possible to avoid safety precautions that would be required for gases having a higher oxygen content.

The invention can be modified in various ways. Any or all of the elements in the Figure labeled "optional" can be omitted or included. The oxygen-enriched air can be used to support various kinds of in-situ combustion processes, not just the THAI or THAI/CAPRI processes. These modifications, and others which will be apparent to those skilled in the art, should be considered within the spirit and scope of the following claims.